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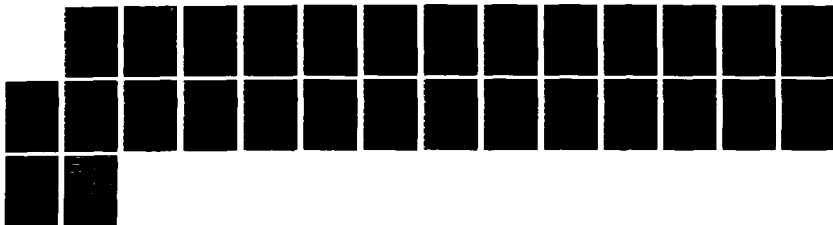
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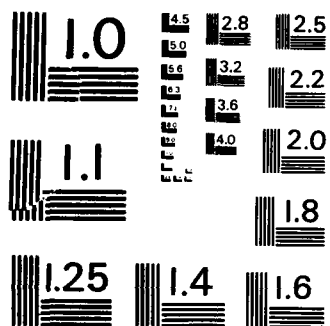
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## **STANDARDIZATION OF EMP HARDENING FOR AIRCRAFT**

**E. F. Vance  
SRI International  
333 Ravenswood Avenue  
Menlo Park, CA 94025-3434**

**31 December 1984**

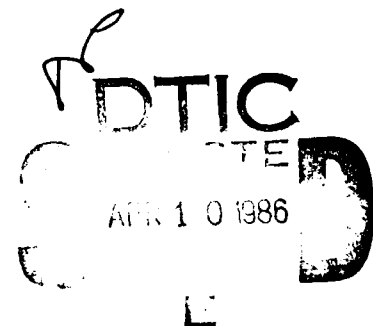
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## PREFACE

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## SECTION 1

### INTRODUCTION

Standardization of requirements for EMP-hardened aircraft is desired to ensure that the hardness achieved in new aircraft is effective and economically incorporated into the aircraft design. With standardization, the procuring agency and the designer/manufacturer can agree at the outset of a system development on these requirements and on how the achievement of the requirements will be determined. The manufacturer is then free to design the most economical means of meeting these requirements, and the buyer is assured that the requirements will be met (if the test of achievement is adequate). The buyer assumes the responsibility for adequately specifying the requirements and the method by which achievement will be measured or tested; the seller assumes the responsibility for meeting the requirements (passing the test).

To prepare standards for hardening aircraft against the EMP, it is necessary to know:

- (1) That hardening is possible
- (2) How to determine whether an aircraft is hard.

Neither of these is as simple as it initially seems; it is usually assumed that hardening is possible, but no tests or analyses of aircraft have been so thorough that all questions are dispelled. Thus, because there is uncertainty in the ability to determine that an aircraft is hard, there is necessarily some uncertainty in the ability to achieve hardness. Nevertheless, it is believed that there are ways to design the hardening of aircraft (and other systems) that permit a fairly rigorous determination of EMP hardness. Since the buyer's protection derives from his ability to test the seller's claim of having achieved hardness, standardization of EMP hardening implies a requirement that the hardening design be amenable to fairly rigorous evaluation. Thus, although the hardening approach is the prerogative of the seller, hardening approaches that are very difficult or impossible to verify must be excluded.

In addition, the way that aircraft systems and avionic subsystems are manufactured and procured suggests that EMP hardening requirements can be allocated between the system level and the avionics, or subsystem, level. Thus, we may have EMP hardening requirements at the system level, at the subsystem level, or both. Hence, we need a rationale for determining whether to require the hardening at the system level, at the subsystem level, or distributed between these levels, and in the latter case, we must evaluate the propriety of various possible allocations between the system and subsystems. Generally, because the EMP-induced stress at the subsystem level depends on the peculiarities of the system-level structure, we can determine system hardness only with system-level requirements and tests.

It is also highly desirable that the EMP hardening not degrade the performance (e.g., reduce range, payload, maneuverability, and utility), that it not reduce the mean time before failure, that it not add disproportionately to the cost of operation and maintenance, and that it not be readily susceptible to compromise or abrogation.

In addition, the EMP hardening must be amenable to reevaluation throughout the life of the system. This requirement arises from the fact that the system hardness may change, and it will not likely experience the EMP during peacetime, yet it will almost certainly be exposed to the EMP during a nuclear engagement. Thus, it is necessary to provide some feedback on the performance of the hardening throughout the long periods when the system is not exposed to the EMP. Generally, in the interest of meeting the cost, reliability, maintainability, and noninterference-with-performance goals discussed above, the number of features that are critical to EMP hardness should be minimized to reduce the possibilities for failure and to reduce the number of features that must be monitored and maintained.

## SECTION 2

### SYSTEM REQUIREMENTS

The requirements of an EMP-hardened system are those features of the system that, if they exist, ensure that the system will be adequately immune to the effects of the EMP. In the abstract, the requirement is that the electromagnetic stress,  $S$ , be smaller than the threshold,  $T$ , for malfunction at all points in and about the system, as illustrated in Figure 1. Since the stress and threshold can have different values at each point in space, such a general requirement is not useful in standardization of EMP hardening. Somewhat more useful might be the requirement that the EMP-induced stress in each circuit be less than the threshold of the circuit for every system and circuit state and for all modes of excitation. For systems containing large numbers of circuits and circuit states, even this requirement is difficult to apply and control.

An alternative approach is to partition space in such a way that we can make general statements about entire volumes of space (Figure 2), instead of treating each point or circuit individually (1). For example, we can reduce the effects of external sources to arbitrarily small values inside a shielded volume if the shield is closed and continuous (free of holes or other discontinuities). As a practical matter, fairly thin ( $< 1$  mm) shields of common metals can limit high-altitude EMP-induced voltages in single-turn internal circuits (Figure 3) to less than 0.1 V if the shield is closed and continuous (2). If no internal circuit or device malfunctions with transients of 0.1 V or less, we would not need to evaluate the stress/threshold relation at each interior point; our only requirement would be that the shield is closed, continuous, and of adequate thickness and that the internal circuits will indeed tolerate the 0.1 V transient (or some other known safe value). It is also assumed that nothing outside the protected volume can cause failure (Figure 4). If the stress outside the system causes fire, explosion, flooding, etc, which lead to system failure, the protection provided by the barrier will be negated.

If we punch holes in the shield and pass power and signal wires through some of the holes, we can no longer be assured that EMP-induced voltages on the internal circuits will be less than the known safe value. Nevertheless, if the shield without the holes is adequate (i.e., allows only negligible interior effects to be induced),

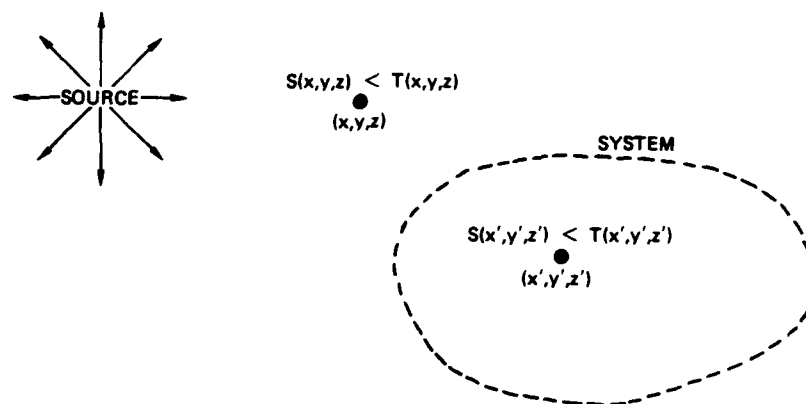


Figure 1. General condition for hardness.

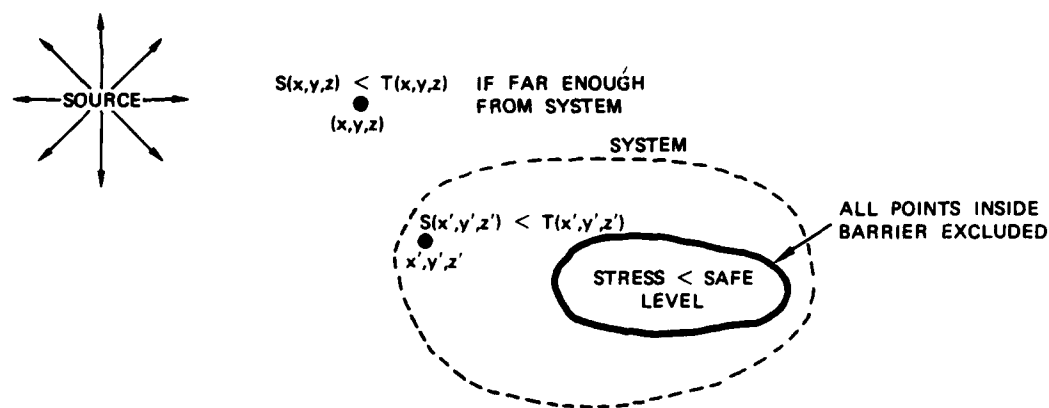


Figure 2. Exclusion of volumes in which stress is controlled and safe.

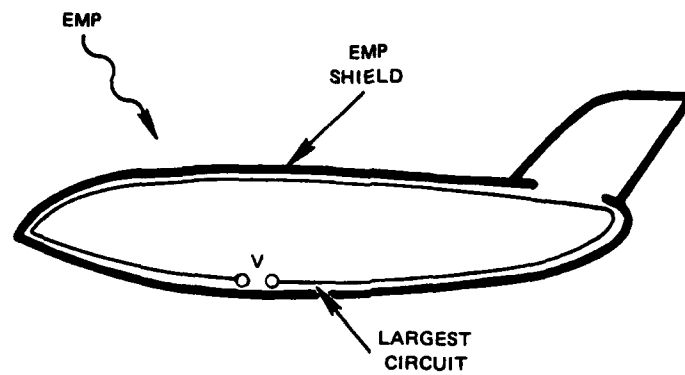


Figure 3. Method by which EMP-induced interior voltage can be arbitrarily minimized.

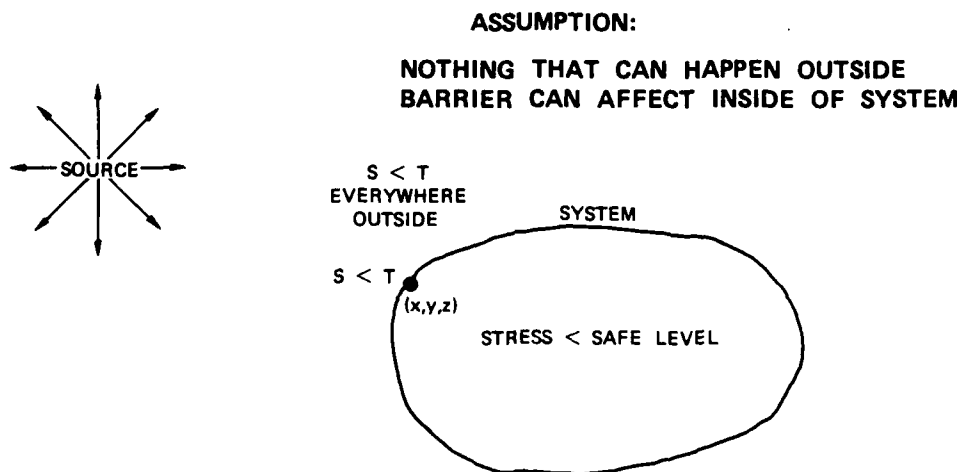


Figure 4. Condition on safe volume protected by barrier.

we need be concerned only with the effects of the holes; we do not need to place additional requirements on the rest of the shield. That is, the requirement for hardness is that the shield be closed, continuous, and of adequate thickness everywhere except at the holes, and that the interior stresses induced by the EMP interacting through the holes be less than the threshold for malfunction for the interior circuits and devices.

Since the EMP-induced effect at any point, device, or circuit inside the shield is a composite of the effects induced through each hole (as illustrated in Figure 5), specification of the hardness requirements can be much more complicated when many holes in the shield are allowed, unless it can be ensured that the internal stress cannot exceed the known safe value. On the other hand, if the EMP-induced stress can exceed the known safe value, evaluation of the system hardness implies evaluating these composite stresses for all interior circuits, circuit states, and modes of excitation. Furthermore, maintenance of hardness requires some kind of reevaluation, or monitoring, of these stress reductions throughout the life of the system. Nevertheless, system hardness can, in principle, be determined either by demonstrating that the EMP barrier is adequate or by demonstrating that the internal stress is tolerable.

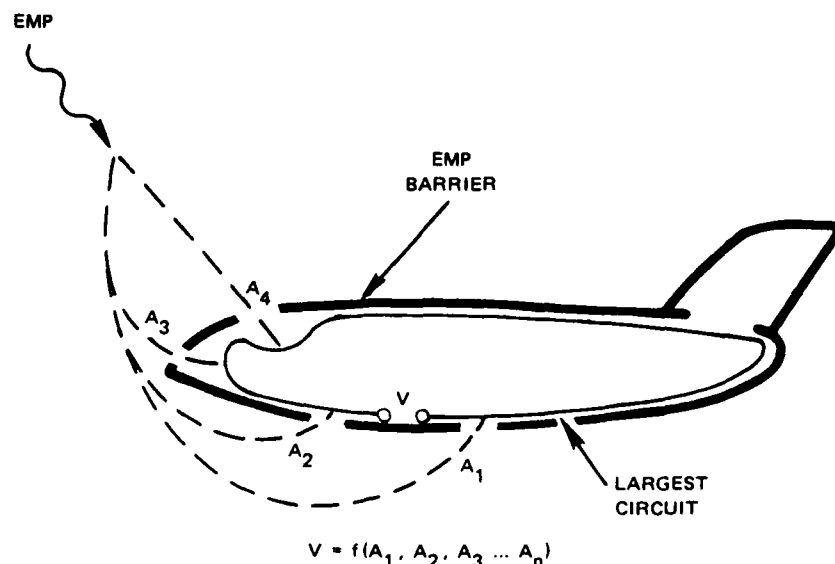


Figure 5. Interaction paths through imperfections in shield.

For standardization of EMP hardening requirements without stipulating the hardening design, it appears that one test of compliance could be a demonstration that the stress induced on each circuit and each component by all EMP interaction paths (as illustrated in Figure 5) is less than the known tolerance of the circuit and component. Exceptions could be permitted as follows:

- (1) If it can be demonstrated that no EMP-induced stress within a shielded volume is greater than the known safe value for components or circuits inside the volume, this demonstration is not required inside shielded volumes.
- (2) If it can be demonstrated that the circuit or component is not essential to the mission or function being protected, and that there is no way that the nonessential circuit or component can cause essential circuits or components to malfunction or be degraded by the EMP, the test of compliance can be waived.

For systems protected with a continuous metal shield, such as a ground-based facility with a welded steel shield, Exception 1 would probably be invoked more often than the basic requirement, since Exception 1 makes the individual validation of large numbers of circuits, states, etc., inside a system-level EMP barrier unnecessary. That is, it allows all internal circuits and components to be validated by establishing the appropriate conditions at the system-level barrier; determination of the stresses and thresholds for each circuit, state, and mode of excitation is made unnecessary. Furthermore, it allows the designer to treat shielded subsystems as protected volumes rather than as large agglomerations of circuits and components.

Thus, a practical alternative for well-shielded systems is to require that the EMP barrier limit the EMP-induced stress to a level below the known safe value for interior circuits and components. The test of compliance would be a demonstration that the EMP-induced stress inside the barrier is less than the known safe stress for the internal circuits and components. For any circuits not protected by a barrier meeting this requirement, it must be demonstrated that:

- (1) The stress applied to the circuit or component by the EMP is less than the known safe value for the circuit or component.
- (2) The circuit or component is not essential to the mission or function being protected, and that the nonessential circuit or component cannot cause essential circuits or components to malfunction or be degraded by the EMP.

This approach to specifying hardness requirements may be somewhat more direct (than the first approach) for many practical hardening approaches that are based on providing an EMP barrier enclosing all or most of the essential circuits and components.

## 2.1 SAFE STRESS VALUE (ALLOCATION OF PROTECTION).

The above paragraphs imply that a stress level exists at or below which no undesired effect on the system circuits or components is produced. This safe value of stress may be defined in several ways: the level at which damage occurs (or is just avoided), the level at which upset occurs, the level to which the circuits and components are normally exposed and operated, and others. In choosing a threshold or safe stress level for internal circuits or equipment, one is also allocating the EMP protection between the system and the internal components of the system. Some of these allocations require more knowledge, maintenance, surveillance (or other care), and understanding than others.

For purposes of standardization, it is important that the safe value of stress be known or controlled throughout the life of the system or that the tolerance be frequently or continuously tested. For example, the damage level for components is not specified or controlled by component manufacturers, and there is no guarantee that at some time during the life of the system one component will not be replaced by another with a lower damage threshold. Hence, considerable overdesign is often used to allow for such uncertainties. These and other failure thresholds (or safe stress values) are discussed in more detail in Refs. 3 and 4.

From the standpoint of system maintenance and surveillance, there are major advantages to reducing the EMP-induced stress inside the system-level barrier until it is no longer the dominant stress in this region. This condition would exist if transients generated by the system itself were larger in all important respects than the EMP-induced transients. Then these system-generated transients would stress all interior elements of the system more than the EMP would, and any degradation in tolerance would be revealed by the peacetime stresses; in fact, our EMP requirement on interior elements is that they withstand the peacetime operating stresses.

On the other hand, these internally generated transient stresses are not well controlled at present, and we do not have much data on the properties of these transients. Some effort would be required to establish the system-generated transient characteristics and to apply these to hardening designs without overdesigning to accommodate uncertainties in source characteristics. It seems reasonably certain that some level of system-generated transients exists, and there is evidence that this level is fairly large. Since such transients are not controlled and are not likely to become carefully controlled, it is necessary to establish controlled transient-tolerance requirements on electrical and electronic equipment. The chosen



transient-tolerance level should be compatible with typical onboard peacetime environments (which are probably not greatly affected by EMP hardening), so that existing equipment is not necessarily made obsolete by the transient requirement. That is, the transient stress that such equipment should be required to withstand should be close to, but somewhat greater than, the typical stress encountered in current aircraft so that:

- (1) Most existing equipment would meet the requirement without modification.
- (2) The cost of designing new equipment to meet the transient requirements is minimized.

There are important advantages to maintaining a large degree of interchangeability between the existing inventory of equipment (particularly avionics) and new equipment meeting the transient specification.

First, the cost of maintaining two inventories -- one for older equipment to support existing aircraft, and another for transient-tolerant equipment to support EMP-hardened equipment -- or replacing the existing inventory with new, upgraded equipment is significant. (The cost of the avionics is a large fraction of the total cost of modern military aircraft).

Second, the maintenance problems associated with having two functionally interchangeable units in stock -- one acceptable for use in hardened aircraft and one forbidden -- are formidable. One can predict almost with certainty that at some point in the life of a hardened system the functionally interchangeable forbidden unit will be substituted for a failed transient-tolerant unit to return an expensive system to operational status. If the EMP hardness depends on the transient tolerance of the unit, the system will sooner or later lose its EMP hardness.

Third, there is no need for strict configuration control inside the system-level barrier, since the EMP-induced stress is weaker than the system-generated stress. In addition, new subsystems can be added in future modernization programs, as long as the new equipment is placed inside the system-level EMP barrier and will tolerate the peacetime stresses. These advantages are, of course, contingent upon the changes in configuration and equipment not changing the system-generated stresses sufficiently to upset the condition that the EMP-induced stress is smaller than the system-generated stress.

Finally, if the transient tolerance required of the interior unit for EMP hardness is comparable to or less than the existing system-generated transient environment, the EMP surveillance of the interior units will be performed by the

system during ordinary peacetime operation. That is, a degradation in the transient tolerance of a unit will be apparent as a malfunction during normal operation, since during normal operation the unit must tolerate system-generated transients larger than those produced by the EMP. This can greatly reduce the number of hardness features that must be monitored and maintained to preserve the system hardness.

## 2.2 PROPERTIES OF TRANSIENT STRESS.

The above discussion also implies that we can adequately describe transient stress, measure it, and compare one stress to another. In an abstract sense, the transient stress may be thought of as the electromagnetic fields applied to all points in the system throughout all time by an incident or impressed electromagnetic wave. When the system is completely enclosed in a metal shield, the stress on the shield may be taken as the charge density and current density at each point on the shield throughout all time.

As noted above, if the shield is closed and continuous, the internal effects of the EMP-induced stresses can be made arbitrarily small inside the shield. Then only the wires penetrating the shield and the openings or other discontinuities in the shield are important in permitting significant internal stresses to be induced by the external EMP. Stress on the penetrating wires can usually be represented by the voltage and current on the wire (throughout all time), and the stress of most concern on interior wiring and cabling is the voltage and current on these wires and cables (fields inside a good shield are almost entirely attributable to currents and voltages on interior wiring). Practical characterization of transient stress usually implies characterization of transient currents and voltages on system wiring, rather than fields inside the shield.

Although continuous-wave stress may be adequately described by an amplitude and a frequency, transient stress is more complex. In general, the spectrum of a transient contains an infinite number of frequencies, each with a different phase and amplitude. It is apparent that we cannot specify transients by defining the amplitude, phase, and frequency of each constituent of the transient spectrum. It is equally impractical to specify the amplitude and time throughout the transient waveform. However, single parameters (such as peak current or energy) are probably inadequate descriptions of transient stress.

As noted in Ref. 3, the important characteristics of transient voltage or current waveforms are those that produce undesirable responses, such as upset or dielectric

breakdown, in the system components. Some of these characteristics of transient waveforms have been identified in Ref. 3, and corresponding frequency-domain characteristics have been discussed in Ref. 6. The time-domain properties of transient stress include:

Table 1. Transient stress properties.

Characterization	Application
Rate of rise	Mutually coupled circuits, including coupling through apertures
Peak Value	Dielectric breakdown (insulation damage, arcing, junction breakdown)
Impulse	Digital circuit switching
Power, action, energy	Directly induced damage to electronic components
Rectified impulse	"Stacking" circuits that rectify and accumulate oscillatory waves
Dominant oscillations	Frequency-selective circuits

One possibility for characterizing transient stress is to describe the above properties (and such others as may be deemed important) of the transient currents and voltages on system wiring. Both the transient stress used to qualify an avionics unit for transient tolerance and the transient stress induced on interior wiring by the EMP could be described by the values of these characteristics. In general, hardness is indicated when, at all points in the system or subsystem, the first four parameters for the EMP-induced stress are smaller than the corresponding values for transient tolerance, and the induced stress contains no oscillations that trigger tone-selective or stacking circuits in the qualified avionics.

Although the fields inside a well-shielded system are dominated by those about wires and cables, standards for equipment should require a demonstration that the equipment will tolerate impressed fields, as well as voltages and currents on its input/output cables. Such a demonstration is required to ensure that equipment housed in nonmetallic cases will indeed tolerate fields impressed on the internal circuits by EMP-induced wire and cable currents.

### SECTION 3

#### EVALUATION OF HARDNESS

After a system is designed and built, it must be tested to verify that it is indeed hard. The principal standardization effort is devising a test that can determine whether or not the system is hard without making too many assumptions about how hardness is achieved. Just as our goal in writing hardness requirements was to establish what features a hard system must possess, our goal in evaluating hardness is to determine whether or not the completed system possesses those features. Neither the requirements nor the evaluation should dictate the hardening design; if the buyer specifies the design, he assumes the responsibility for its performance (or lack thereof).

On the other hand, we can exclude those hardening approaches that are so complicated that even extensive testing cannot develop conclusive evidence of system hardness; one requirement of the hardening design must be that its effectiveness can be demonstrated with available or economically obtainable facilities.

The evaluation of system hardness may consist of determining that:

- (1) The EMP barrier reduced the internal stresses to a known safe level everywhere inside the barrier.
- (2) The EMP-induced stress at the boundaries (terminals) of the equipment in the system is below the known safe level for the equipment.

The first approach is directed toward evaluating the adequacy of the barrier (Figure 6). If it can be shown that the EMP barrier is effective enough, all equipment, circuits, etc., inside the barrier will be protected. This approach is useful and conclusive if the barrier is simple and sufficiently effective that no objectionable stresses are allowed to penetrate the barrier or be built up, released, or triggered inside the barrier by the EMP. For example, if the barrier is continuous metal except for a small number of controlled apertures and wire penetrations, the hardness can be evaluated by measuring the maximum transient stresses delivered to the interior by the wires and apertures, and determining that these cannot exceed the transient tolerance of any interior elements of the system (assuming that all critical elements of the system are inside the EMP barrier).

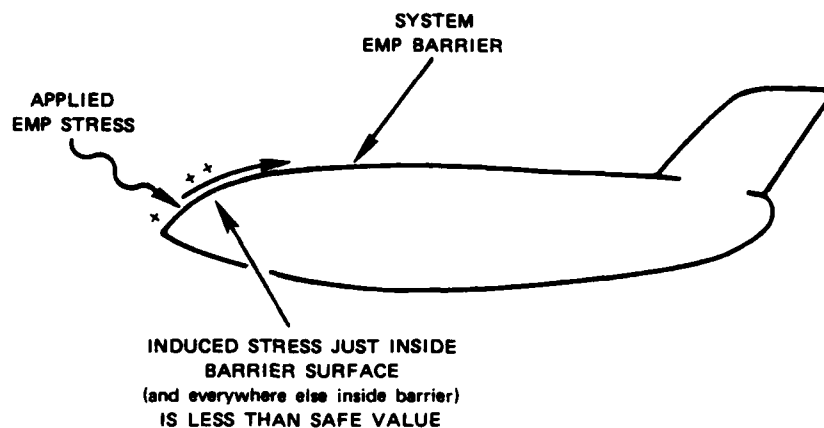


Figure 6. Determining effectiveness of EMP barrier.

In the case of a simple barrier (few apertures or penetrating wires), the evaluation can be fairly simple and conclusive, since only a few interaction paths are to be assessed. However, if the barrier is very complicated, the evaluation of its effectiveness can also be complicated. If the barrier contains many wire, cable, and plumbing penetrations, or many protruding sections of shielded cable with connectors, splices, etc., or many gasketed joints and other discontinuities, it will be difficult to determine that the EMP barrier is adequate by measuring barrier properties alone.

The second approach is equipment-oriented; it seeks to ensure that the essential equipment is not stressed more by the EMP than its known transient tolerance level. Thus, the stress is measured at or near the terminals of each item (unit, rack, subassembly) of equipment, as suggested in Figure 7, rather than at the system-level EMP barrier. It is stipulated that if the EMP-induced stress at the equipment terminals is less than the known safe stress for the equipment, for each item of equipment in the system, then the system is hard. It is usually understood, though often not stated, that no malfunctions outside the equipment housings are permitted; that is, system wiring and other structure may not breakdown or otherwise cause a system malfunction as a result of the applied EMP stresses.

A thorough test at the terminals of the equipment is often difficult because of the large numbers of terminals (pins) and the larger number of system states that can

affect the interaction. For large aircraft, the number of pins may be of the order of 10,000, and the number of states of the system may be  $10^{100}$ . It is difficult to test this many conditions even with automated test equipment, and it is equally difficult to establish a rigorous statistical description of the system, since an accurate statistical description also requires tests of large samples from current production lots.

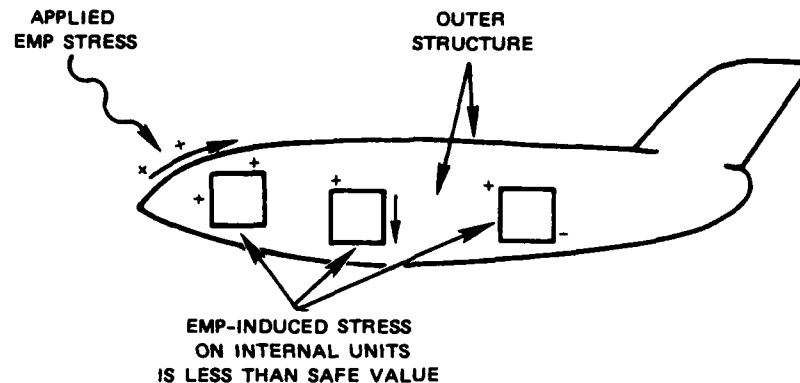


Figure 7. Determining safe stress on internal equipment.

In past programs, EMP-induced stress and transient tolerance were compared at the bulk current level. That is, the total current induced in the wire bundle by simulated EMP was measured, and that level (or larger) was injected onto the cable to ensure that the equipment would tolerate that stress. This method greatly reduces the number of measurements required, but it suffers from a lack of rigor in relating the bulk current to the pin tolerances. When done in situ on a system with a good system-level EMP barrier, however, the direct injection test is probably representative of the stress applied to the cables by the incident EMP. The problem of the number of states can be at least partially circumvented by injecting a repetitive pulse while the system is energized and operating in its normal states. By injecting several thousand pulses without malfunction, some confidence is gained in the hardness of the system.

## SECTION 4

### SUPPORTING DOCUMENTS

#### 4.1 SPECIFICATIONS FOR INTERIOR COMPONENTS.

Regardless of how system hardening is specified, the transient tolerance of interior wiring, cabling, electrical components, avionics etc., must be specified to support the system hardening design. If sufficient protection is allocated to the system EMP barrier so that the EMP-induced stress is not the largest stress inside the barrier, present specifications will be adequate for most interior materials and components. For avionics and electrical equipment, which currently have only limited transient-tolerance requirements, new transient-tolerance requirements for EMP must be applied.

As noted in the discussion of safe stress value, the transient-tolerance requirements on interior equipment will depend on how the EMP protection is allocated between the system-level structure and the interior. However, the interior equipment must tolerate at least the peacetime transient stresses inside the system, and there are important advantages in basing the transient-tolerance requirements on the peacetime transient stresses, so that *most* existing equipment can meet the EMP requirements, and the logistic problems of stocking and accounting for several versions of the same unit are avoided.

The transient tolerance of interior equipment must be specified and characterized in the same way that the EMP-induced stress is specified and characterized. That is, the unit tolerance for rate of rise, peak value, action, and any other characteristic of a transient that might be important, must be specified. Furthermore, if the transient tolerance is specified by pin voltages and currents, the EMP-induced stress must be specified by the same quantities (unless a well-established relation exists between the measure of tolerance and the measure of stress). Thus, for example, tolerance should not be specified by pin voltages and currents if the stress is specified as bulk (bundle or cable) currents and voltages. In addition to power and input/output terminal specifications, as noted above, the interior equipment must have a specified tolerance for transient fields, since there will be EMP-induced fields inside the aircraft.

Two or more classes of equipment may be required to meet all system needs. Thus, for example, the transient tolerance required of equipment installed inside the EMP barrier is less stringent than the tolerance required of equipment installed outside

the barrier. Requiring all equipment to tolerate the environment outside the barrier would probably not be economical because of the cost, weight, and reliability penalty that would be incurred.

#### 4.2 DESIGN GUIDELINES.

Although the EMP standard should not specify how the hardening is to be achieved, potential bidders should be provided with guidance on how hardening can be achieved. Such guidance is frequently provided in the form of MIL-HANDBOOKs and design guidelines, which provide guidance on how particular features of a system can be designed, but do not ordinarily dictate the design details to such an extent that the contractor is relieved of responsibility for the performance of his design. Some handbooks on EMP effects on aircraft and missiles are available, but for the most part, these are oriented toward the analysis of EMP interaction. A need remains for a design-oriented handbook. A design guide should enumerate and describe the accepted ways of treating various aspects of EMP hardening design. It should explain the advantages, disadvantages, relative effectiveness, and limitations of each technique and device and, where important, explain cumulative and synergistic effects and uncertainties, such as those associated with using large numbers of nonlinear devices. It should also explain the nuances of hardness validation, so that the requirement to design hardness capable of being validated can be met.

#### 4.3 COMPONENT SPECIFICATIONS.

EMP barriers are constructed from many components -- shields, connectors, braided wire, conduits, filters, surge arresters, etc. Some of these do not currently have specified transient properties suitable for determining their performance in EMP hardening applications. Others have specified broadband properties that are not useful in evaluating the component as a barrier element. Hence, some additional specifications and standards will be required to support the production of hardened aircraft. Among the more important are:

Shield Evaluation. No standard method exists for determining the effectiveness of a shield in preventing an external source from interacting with an internal circuit. Hence, it is difficult to determine whether a shield is adequate before it is filled with equipment and exposed to an external source. (MIL-STD-285 measures the insertion loss when the shield is inserted between two antennas; it is not possible to



obtain the interaction between an external source and an internal circuit from the "shielding effectiveness" so determined.)

Power Line Filters. Power line filters are specified in terms of their insertion loss in a 50-ohm circuit. In use, neither the load nor the source impedances are 50 ohms; hence, it is not possible to predict the performance of the filter when transients are applied to the power lines. Furthermore, many of the filters currently available display insertion gains (i.e., the output is larger than the input) at some frequencies when the input impedance is smaller than 50 ohms and the output impedance is larger than 50 ohms. A more dependable method of specifying and testing power filters for transient suppression is needed. The input capacitance, which is important in determining the rise time of the transient excitation, is not presently specified. Neither the leakage current at 60 Hz, which affects ground-fault-current control, nor the tolerance of the filter input for fast transient voltages is specified. All of these parameters are necessary for system protection design using power line filters.

Surge Arrester Specifications. Standards for specifying the performance of surge arresters are needed to provide uniform data on the fast transient performance and energy-handling capabilities of these devices.

Standard Shield Component Criteria. Standards for measuring and specifying the shielding properties of meshes, honeycombs, and conductive coatings for treating apertures in shields are needed.

## SECTION 5

### CONCLUSIONS

The standard for EMP hardening forms a part of the contract between the buyer and the seller; it represents the buyer's expectation and the seller's promise. Although the buyer may specify how to design the hardening, he must assume responsibility for the design if he does. However, if the buyer specifies only how the hardening must perform and leaves the design to the seller, the buyer must be able to specify tests or measurements that will determine whether the delivered product is hard. The buyer and seller must agree on these tests, which become part of the contract between buyer and seller.

The standard for EMP hardening of aircraft should specify the properties of a hard aircraft and the tests or other methods that will be used to determine whether the delivered aircraft has these properties. However, because aircraft are very complex systems and the EMP is a large-amplitude, wide-spectrum transient originating outside the aircraft (and not under its control), not all "hardening" approaches can be rigorously evaluated. Therefore, some practical limits on test time, number of measurements, or cost of hardness verification must be imposed so that the hardness can be verified, even though the design details are left to the seller.

More rigorous evaluation of the EMP hardness is necessary than is usually required for other electromagnetic interference threats. This is because we learn little about the aircraft's ability to resist the nuclear EMP from peacetime operations. Hence, if there is a shortcoming in the EMP hardness, we are unlikely to know of it until the beginning of a nuclear engagement, unless we can rigorously evaluate the hardness initially and throughout the life of the aircraft. Thus, the norm for EMP hardening should be hardening approaches that are simple enough that all failure possibilities can be identified and evaluated, and that the likelihood of unknown failure possibilities is remote.

Since the EMP is impressed on the system from the outside, the entire system must be protected. Although the protection may be distributed between system-level barriers and interior equipment protection, evaluation of EMP effects inside the system are extremely difficult, because the interior stresses depend on the electromagnetically complex, multistate, system-level structure between the source (bomb) and the interior point of interest. Such distributed hardening is almost

impossible to evaluate and maintain, unless the EMP-induced stress inside the system-level barrier is made smaller than some stress to which the interior is routinely exposed (so that the EMP-induced stress is not the dominant stress inside the barrier).

Nevertheless, there is a need for transient-tolerance requirements on interior equipment. Present narrowband tolerance specifications in MIL-STD-461 do not provide adequate assurance of transient tolerance for modern digital circuits. Hence, though it should not be based on EMP stresses, the transient tolerance of interior equipment should be specified, and a safe stress for interior equipment should be determined. It is postulated that the specified tolerance should be based on peasetime stresses produced inside typical aircraft by sources inside the aircraft. Unfortunately, these stresses are not well known at present.

To support an EMP hardening program, desing guidelines and qualified parts must be available to the design community. Thus, a part of the standardization effort will be to provide standards for components used in the hardening of aircraft and to prepare design guides to accompany the EMP standards.

## SECTION 6

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